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Decoherence, Quantum Zeno Effect, and the Efficacy of Mental Effort. *

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Abstract

Recent theoretical and experimental papers support the prevailing opinion that large warm systems will rapidly lose quantum coherence, and that classical properties will emerge. This rapid loss of coherence would naturally be expected to block any critical role for quantum theory in explaining the interaction between our conscious experiences and the physical activities of our brains. However, there is a quantum theory of mind in which the efficacy of mental effort is not affected by decoherence effects. In this theory the effects of mental action on brain activity is achieved by a Quantum Zeno Effect that is not weakened by decoherence. The theory is based on a relativistic version of von Neumann's quantum theory. It encompasses all the predictions of Copenhagen quantum theory, which include all the validated predictions of classical physical theory. In addition, it forges two-way dynamical links between the physical and experiential aspects of nature. The theory has significant explanatory power.

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1. Introduction.

The experimental work of the Paris group of S. Haroche [1] and of the Boulder group of D. Wineland [2] demonstrate convincingly that the theoretical ideas of quantum theory really do work in careful experiments performed, in effect, on individual atoms interacting with controlled electromagnetic probes and environments. It is an impressive tribute to the power of human reason and logic that the creators of quantum theory were able to accurately forecast effects so far removed in scale and intricacy from the data that they possessed.

The experiments of these groups both confirm the emergence of decoherence effects whose strength and rapidity of onset increase rapidly with the size of the system being disturbed by interactions with its environment.

In recent theoretical paper [3] Max Tegmark computes, on the basis of the thus-confirmed ideas, some expected time intervals for the disappearance of quantum coherence in various brain structures that have been proposed as the seat of the neural correlates of consciousness. He finds that quantum coherence disappears on time scales of 10^{-13} to 10^{-20} seconds, and concludes from this that classical concepts should provide a completely adequate basis for understanding the dynamical connection between mind and brain.

This conclusion depends on the idea that the quantum interaction between mind and brain depends upon quantum coherence. It is indeed usually thought that coherence is the essence of quantum theory, and that all quantum effects depend upon it. But the development of the von Neumann-Wigner quantum theory of mind pursued by this author was specifically designed so that the effect of mental effort on brain process is not weakened by decoherence. Indeed, quantum decoherence was *assumed* to decompose the state of the brain into a mixture of essentially classical states. But the quantum effect of mental effort on brain activity is not curtailed by this decomposition.

I shall now explain how this works.

2. Overview of the Theory

Before giving the specific computation I must first describe the general form of the theory. It is based on objectively interpreted von Neumann-Wigner quantum theory. I have argued elsewhere [4,5] that the evolving state S(t) of von Neumann-Wigner quantum theory can be construed to be our theoretical representation of an objectively existing and evolving informational structure that can properly be called "physical reality".

The theory has four basic equations. The first defines the state of a subsystem. If S(t) is the operator that represents the state of the universe and b is a subsystem of the universe then the state of b is defined to be

$$S(t)_b = Tr_b S(t), \tag{2.1}$$

where Tr_b means the trace over all variable except those that characterize b.

The second basic equation specifies von Neumann's process I. This process "poses a question". If $S(t-0)$ represents the limit of $S(t')$ as t' approaches t from below then at certain times t the following jump occurs:

$$S(t) = PS(t-0)P + (1-P)S(t-0)(1-P). \tag{2.2}$$

Here P is a projection operator (i.e., $P^2 = P$) that acts as the unit operator on all degrees of freedom except those associated with the processor b.

The third basic equation specifies the (Dirac) reduction. This reduction specifies nature's answer to the question:

$$S(t+0) = PS(t)P \text{ with probability } TrPS(t)/TrS(t) \tag{2.3}$$

or

$$S(t+0) = (1-P)S(t)(1-P) \text{ with probability } Tr(1-P)S(t)/TrS(t).$$

Between jumps the state evolves according to:

$$S(t+\Delta t) = \exp(-iH\Delta t)S(t)\exp(+iH\Delta t). \tag{2.4}$$

The projection operator P has two eigenvalues, 1 and 0, and is therefore associated with a Yes-No question: the two alternative possible reductions specified in (2.3) are associated with the two alternative possible answers, Yes or No, to the question associated with P. Thus the reduction (2.3) specifies one bit of information, and implants that information in the state S(t) of the physical universe. This state S(t) can be regarded as just the evolving carrier of the bits of information generated by these reduction events.

Information is normally conceived to be associated with an interpreting system. In Copenhagen quantum theory each reduction is associated with an increment in human knowledge, and the interpreting system is the brain and body of the observer. Generalizing from this one known kind of example, I shall assume that each reduction (2.3) is associated with a quantum information processor, call it b, that both poses the question —picks P—and, when nature responds by picking, say, the answer P=1, 'interprets' that bit of information by evolving in a characteristic way.

The projection operator P cannot be local: any point-like projection would inject infinite energy into the processor. This jump of S(t) to P S(t)P, because it is basically a nonlocal process, has no counterpart in classical dynamics: it is a new kind of element, relative to classical physical theory. Generalizing again from the one known example, I assume that each reduction event is connected to some sort of "knowing": each such event has a characteristic experiential "feel".

Each thought involves an effort to attend to something— i.e., to pose a question—followed by a registration of the answer. This conforms exactly to the quantum dynamics.

Normally a sequence of thoughts consists of a string of thoughts each of which differs just slightly from its predecessor: the sequence becomes a 'stream' of consciousness. So the basic process is self-replication: the thought T creates conditions that tend to create a likeness of T.

This means that a key requirement for P is that PSP not evolve rapidly out of the subspace defined by P, or at least that PSP quickly evolve into a

state nearly the same as PSP, so that the sequence of thought is likely to be a sequence of similar thoughts.

One possibility is that the projection operator P may act in the space of a set of conjugate variables that is undergoing periodic motion, and that it projects onto a band of neighboring orbits in phase space. For a simple harmonic oscillator in a state of high energy one could take the projection operator P to be the sum of the projection operators onto a large set of neighboring energy eigenstates. This would effectively project onto a band of neighboring orbits in phase space.

3. The Quantum Zeno Effect

In this theory the main effect of mind on brain is via the quantum Zeno effect. Suppose the initial state is PS(t)P, and that in that state the next question is again P, and that this question repetitiously repeats. If these questions are posed at intervals Δt then equations (2.4) and (2.2) give

$$S(t + \Delta t) = P\exp(-iH\Delta t)PS(t)P\exp(+iH\Delta t)P$$
$$+(1-P)\exp(-iH\Delta t)PS(t)P\exp(+iH\Delta t)(1-P).$$

If Δt is small on the scale of the leakage of PS(t)P out of the subspace defined by P then the second term is small and of second order in Δt. Thus as Δt gets small, on the scale of the leakage of PSP into the subspace associated with $(1-P)$, the Hamiltonian H gets effectively replaced by PHP: evolution within the P subspace proceeds normally, but leakage out of that subspace is blocked.

The point here is that the linear-in-time leakage out of the subspace defined by P is killed by the reduction events. Thus only the quadratic and higher terms survive, and these are damped out if the reductions occurs fast on the time scale of the relevant oscillations.

This replacement of the full Hamiltonian H by PHP is the usual quantum Zeno effect. We see that it is just as effective for a statistical mixture S(t) of quasi-classical states as for a pure state: the decoherence generated by interaction with the environment does not weaken this quantum effect.

4. Explanatory Power

Von Neumann-Wigner quantum theory encompasses all the valid predictions of classical physical theory. So for any computation, or argumentation, for which quantum effects are unimportant one can use classical physics. Hence vN/W theory is at least as good as classical physical theory: the two theories are effectively equivalent insofar as quantum effects are unimportant. In the purely physical domain the vN/W theory is certainly better, because it predicts also all of the quantum effects, including all of the "nonlocal" quantum effects. But our interest here is on the nature of the dynamical link between mind and brain, and the nature of the consequences of this connection.

The only power given to the mind by this theory is the power to choose the questions P. And the only effects of these choices that has thus far been identified are the consequences achieved by the quantum Zeno effect. This effect is to keep the brain activity focussed on a question for longer than it would stay focussed in the classical theory.

To make the theory still more constrained, let me assume that the quantum processor, in this case the human brain/body, possesses a certain set of possible questions P, and that at a prescribed sequence of instants the processor can either consent, or not consent, to posing a certain possible question P. Let this question P be the one that maximizes $Tr_b PS(T)/Tr_b S(t)$. To accomodate our intuitive feeling that mental 'effort' does effect brain/body activity I add the postulate that the rapidity of the sequence of instants can be increased by mental effort.

This is a simple theory. But the effect of mind on brain is highly constrained. The only variables under mental control are "consent' and 'effort'.

Does this theory explain anything?

Consider the following passage from "Psychology: The Briefer Course" by William James [7]. In the final section of the chapter on Attention he writes:

"I have spoken as if our attention were wholly determined by neural con-

ditions. I believe that the array of *things* we can attend to is so determined. No object can *catch* our attention except by the neural machinery. But the *amount* of the attention which an object receives after it has caught our attention is another question. It often takes effort to keep mind upon it. We feel that we can make more or less of the effort as we choose. If this feeling be not deceptive, if our effort be a spiritual force, and an indeterminant one, then of course it contributes coequally with the cerebral conditions to the result. Though it introduce no new idea, it will deepen and prolong the stay in consciousness of innumerable ideas which else would fade more quickly away. The delay thus gained might not be more than a second in duration—but that second may be critical; for in the rising and falling considerations in the mind, where two associated systems of them are nearly in equilibrium it is often a matter of but a second more or less of attention at the outset, whether one system shall gain force to occupy the field and develop itself and exclude the other, or be excluded itself by the other. When developed it may make us act, and that act may seal our doom. When we come to the chapter on the Will we shall see that the whole drama of the voluntary life hinges on the attention, slightly more or slightly less, which rival motor ideas may receive. ..."

Posing a question is the act of attending. In the chapter on Will, in the section entitled "Volitional effort is effort of attention" [7] James writes:

"Thus we find that *we reach the heart of our inquiry into volition when we ask by what process is it that the thought of any given action comes to prevail stably in the mind.*"

and later

"*The essential achievement of the will, in short, when it is most 'voluntary,' is to attend to a difficult object and hold it fast before the mind. ... Effort of attention is thus the essential phenomenon of will."*

Still later, James says:

"Consent to the idea's undivided presence, this is effort's sole achievement." ..."Everywhere, then, the function of effort is the same: to keep

affirming and adopting the thought which, if left to itself, would slip away."

The vN/W theory, with the quantum zeno effect incorporated, explains naturally the features that are the basis of James's conception of the action of human volition.

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